

Neutrino Physics and A_4 matter assignments

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Summary. — Tribimaximal lepton mixing can be obtained assuming A_4 flavour symmetry. Many possibilities have been explored in the literature and we give a classification in terms of A_4 representations. We propose some phenomenological and theoretical criteria to distinguish between different assignment. As example we consider the possibility to extend A_4 to $SO(10)$ grand unified model.

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1. – Introduction

It is an experimental fact that atmospheric, solar, reactor and accelerator neutrinos change flavour. The present data [1] give the solar lepton mixing angle $\sin^2 \theta_{12} = 0.32$ with a relative error about of 25%(@ 3σ), the atmospheric angle $\sin^2 \theta_{23} = 0.5$ with a relative error about of 34%(@ 3σ) and $\sin^2 \theta_{13} \leq 0.05$ (@ 3σ). The complex phase has not been measured. Precise future data might confirm the maximality of the atmospheric angle within 10% error. The best fit values agree very well with the so called Tri-Bimaximal (TB) lepton mixing matrix [2] where the atmospheric angle is maximal $\sin^2 \theta_{23} = 1/2$, the solar angle is large $\sin^2 \theta_{12} = 1/3$ and $\sin^2 \theta_{13} = 0$. Assuming the charged lepton mass matrix M_l diagonal, $U_{\text{TB}} \cdot \text{Diag}[m_1, m_2, m_3] \cdot U_{\text{TB}}^T$ takes the form

$$M_\nu = \begin{pmatrix} \frac{2m_1}{3} + \frac{m_2}{3} & \frac{-m_1}{3} + \frac{m_2}{3} & \frac{-m_1}{3} + \frac{m_2}{3} \\ \frac{-m_1}{3} + \frac{m_2}{3} & \frac{m_1}{6} + \frac{m_2}{3} + \frac{m_3}{2} & \frac{m_1}{6} + \frac{m_2}{3} - \frac{m_3}{2} \\ \frac{-m_1}{3} + \frac{m_2}{3} & \frac{m_1}{6} + \frac{m_2}{3} - \frac{m_3}{2} & \frac{m_1}{6} + \frac{m_2}{3} + \frac{m_3}{2} \end{pmatrix} \equiv \begin{pmatrix} a & d & d \\ d & b & c \\ d & c & b \end{pmatrix}$$

Here M_ν has two important properties: *i*) it is $\nu_\mu \leftrightarrow \nu_\tau$ invariant, so $\theta_{13} = 0$ and the atmospheric angle θ_{23} is maximal and *ii*) $a = b + c - d$ so from the relation

$$\sin^2 2\theta_{12} = \frac{8b^2}{(a - b - c)^2 + 8b^2}$$

(that is always true for $\nu_\mu \leftrightarrow \nu_\tau$ invariant mass matrices [3]) we have that $\sin^2 \theta_{12} = 1/3$. The $\nu_\mu \leftrightarrow \nu_\tau$ invariance in the diagonal charged lepton basis *i*) can be explained with the permutation symmetry S_3 [4], while the relation *ii*) is natural in A_4 models.

| SM | | L_i | l_i^c | ν_i^c | References |
|---------|-----|--------------|--------------|--------------|---------------|
| type-I | I | 3 | $1, 1', 1''$ | 3 | [5, 6, 7, 11] |
| | II | 3 | 3 | $1, 1', 1''$ | [14] |
| | III | $1, 1', 1''$ | 3 | 3 | [15] |
| | IV | $1, 1', 1''$ | $1, 1', 1''$ | 3 | - |
| | V | $1, 1', 1''$ | 3 | $1, 1', 1''$ | - |
| | VI | 3 | $1, 1', 1''$ | $1, 1', 1''$ | - |
| type-II | I | 3 | $1, 1', 1''$ | - | [12] |
| | II | 3 | 3 | - | [13] |
| | III | $1, 1', 1''$ | 3 | - | - |

TABLE I. – *Different A_4 matter assignments for type-I and II seesaw.*

2. – A_4 models and the selecting criteria

A_4 is a finite group of the even permutations of four objects. A_4 is the smallest non-Abelian group that contains a triplet representation. It also contains three distinct singlets $1, 1', 1''$. We can accommodate the three families of fermions both in a triplet and/or in the three singlets representations. In Table I we report all possible assignment with at least one triplet representation. For instance, in ref. [5] A_4 leads to a $\nu_\mu \leftrightarrow \nu_\tau$ invariant neutrino mass matrix, therefore $\theta_{13} = 0$, θ_{23} is maximal and θ_{12} can be fitted within the experimental error. Recently in [6] it has been studied a model that predict also the solar angle. To distinguish these models we need some selecting criteria. One possibility could be to study their *phenomenological* implication:

- the neutrinoless double beta decay rate and the leptonic CP phase;
- the stability under radiative corrections and the deviations from TB mixing;
- LHC phenomenology, for instance, Higgs doublets and/or Higgs triplets.

From the *theoretical* point of view we have at least two general criteria:

- extend A_4 to the strong sector without spoiling the TB mixing: explicitly breaking A_4 [7]; assign q_L and q_R differently to $A_4 \times Z_{n_1} \times \dots Z_{n_k}$ [8]; extra dimensions [9];
- extend the A_4 symmetry to grand unified models (GUT) [9, 10, 16].

3. – A_4 and $SO(10)$ grand unified model

In $SO(10)$ all the SM matter fields belong to one 16-multiplet. Neutrinos get small masses in a natural way through the seesaw mechanism since the right-handed neutrinos get Majorana masses at the unification scale while the Dirac masses can have values at the electroweak scale. $SO(10)$ forces to assign left and right handed fields in one triplet of A_4 giving strong constraints in the model building. First we give an example at the electroweak scale compatible with such a matter assignment. Consider the following

| SM | L_i | l_i^c | N_i^c | ϕ | ϕ' | ξ_1 | ξ_2 |
|-------|----------|----------|------------|----------|------------|----------|------------|
| A_4 | 3 | 3 | 3 | 3 | 3 | 1 | 1 |
| Z_3 | ω | ω | ω^2 | ω | ω^2 | ω | ω^2 |

At the leading order ϕ and ϕ' interact respectively only with the charged and neutral sectors. When $\langle \phi \rangle \sim (1, 1, 1)$, M_l is diagonalized from the magic matrix U_ω , see [14]. If

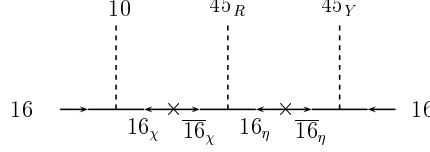


Fig. 1. – Six dimension operator distinguishes up quarks and Dirac neutrinos.

$\langle \phi' \rangle \sim (1, 0, 0)$, in the diagonal charged lepton basis we get

$$M_\nu = m_D \frac{1}{M_R} m_D^T \equiv \begin{pmatrix} 2b/3 + a & -b/3 & -b/3 \\ -b/3 & 2b/3 & -b/3 + a \\ -b/3 & -b/3 + a & 2b/3 \end{pmatrix}$$

that has the properties *i)* and *ii)*. Here we have used the relation $m_D \sim I$ that is a consequence of the model. Such a relation could be a problem since in $SO(10)$ we expect $m_D \sim M_u \sim I$ that is wrong. This argument seems against $SO(10) \times A_4$. In [16] we have studied the possibility to distinguish up quark and Dirac neutrino through dimension six operators showed in Fig.(1) where $16_{\chi, \eta}$ are extra messenger fields. When the adjoints 45_R and 45_Y take vev respectively along weak isospin and the hypercharge, such operator do not contribute to the Dirac neutrino.

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REFERENCES

- [1] MALTONI, SCHWETZ, TORTOLA AND VALLE, *New J. Phys.*, **6** (2004) 122; FOGLI, LISI, MARRONE AND PALAZZO, *Prog. Part. Nucl. Phys.*, **57** (2006) 742
- [2] P. F. HARRISON, D. H. PERKINS AND W. G. SCOTT, *Phys. Lett. B*, **530** (2002) 167;
- [3] F. CARAVAGLIOS AND S. MORISI, hep-ph/0503234;
- [4] W. GRIMUS AND L. LAVOURA, *JHEP*, **0508** (2005) 013;
- [5] BABU, MA, VALLE, *PLB*, **552** (2003) 207;
- [6] ALTARELLI, FERUGLIO, *NPB*, **720** (2005) 64;
- [7] MA, *MPLA*, **17** (2002) 627;
- [8] HE, KEUM AND VOLKAS, *JHEP*, **0604** (2006) 039; BAZZOCCHI, KANEKO AND MORISI, *JHEP*, **0803** (2008) 063;
- [9] ALTARELLI, FERUGLIO AND HAGEDORN, *JHEP*, **0803** (2008) 052;
- [10] GRIMUS AND KUHBÖCK, *PRD*, **77** (2008) 055008; KING AND MALINSKY, *PLB*, **645** (2007) 351; MA, SAWANAKA AND TANIMOTO, *PLB*, **641** (2006) 301;
- [11] BABU, HE, hep-ph/0507217;
- [12] MA, *PRD*, **70** (2004) 031901;
- [13] HIRSCH, MA, VILLANOVA, VALLE, *PRD*, **72** (2005) 091301; MA, *MPLA*, **21** (2006) 2931; MA, *MPLA*, **22** (2007) 101;
- [14] MA, *MPLA*, **20** (2005) 2601;
- [15] HIRSCH, JOSHIPURA, KANEKO, VALLE, *PRL*, **99** (2007) 151802;
- [16] S. MORISI, M. PICARIELLO AND E. TORRENTE-LUJAN, *PRD*, **75** (2007) ;